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Radiation Hazards and the Cancer Risk Assessments in the Sediments of Timsah Lake, Egypt

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Abstract. Timsah Lake is one of the most fish productive lakes in Egypt. It is located at the midpoint of Suez Canal with surface area of about 16 km^2. The lake receives about 833,000 m^3 daily of wastewater and sewage wastes from agriculture, industry and domestic drains. The activity concentrations of the natural radionuclides; ^{238}U, ^{232}Th and ^{40}K were measured using gamma-ray spectrophotometer at 24 stations covering the whole area of the lake and the Western Bay. The average activities of ^{238}U, ^{232}Th and ^{40}K were; 21.66 ± 11.20, 21.42 ± 11.68 and 200.30 ± 141.10 Bq/kg respectively. The averages of radiation hazard parameters; the absorbed and effective dose rate (D), the annual effective dose equivalent (AEDE), radium equivalent (Ra_{eq}), the external hazard index (H_{ex}) and the representative level index (Iγr) were; 30.85 nGy h^{-1}, 37.84 µSv/y, 67.02 Bq/kg, 0.18 (lower than the unity) and 0.23 respectively. The distribution patterns showed significant high variations in the radionuclides activities and the hazard parameters between the investigated stations. The Western Bay stations and the path zone interlinked between the bay and the lake showed the high radionuclide activities and high radiation hazards indicating to the sewage wastes and wastewater runoff are the essential sources of the high natural radionuclide activities and radiation hazards. The average of the excess lifetime cancer risk (ELCR) was 132.43 × 10^{-6} significantly lower than the worldwide average. The highest recorded level of ELCR was reached 308.38 × 10^{-6} observed in the interlink zone between the bay and the lake away from fishing stations and recreational zones. Statistical analyses indicated that the radionuclides ^{238}U and ^{232}Th are the sources of the elevated radiation hazards with nearly equal intensities.

Keywords: Timsah Lake, Suez Canal, Natural radioactivity, Radiation hazards, ELCR risk.

1. Introduction

Due to the high technology that evolved in some industrial techniques, the activity levels of some natural radionuclides in the products and their wastes were much higher than that in the ore and raw materials (El- Abozeed *et al.*, 2017). The high levels of the naturally occurring radioactive materials (NORM) and the continuous exposure to these materials have been identified in many huge industries as energy production using fossil fuels, phosphate industry, oil and gas production (UNSCEAR, 1993).On the other hand, many other sources and operations as; mining, phosphate fertilizers manufacturing, agricultural applications, cement production and applications in addition to many other industrial activities have produced and redistributed elevated radioactive concentrations leading to a considerable contribution to the radio-ecological hazards (Ramasamy *et al.,* 2009). The elevated radioactive wastes that originated from these industries released in the environment and hence, the environmental management is required to reduce the short and long-term impacts of these materials on both the environment and population.

The ^{238}U series decay chain starting with radium (^{226}Ra) is the main source of the radiation exposures in many manmade activities. The radiological hazards of natural radionuclides are attributed to the long-term exposure of humans to gamma rays and the inhalation of radon and its progeny that affect the lung tissues (El-Taher, 2012). The external exposure is caused by direct gamma radiation while the inhalation of radioactive inert gases radon (^{222}Rn, a daughter product of ^{226}Ra) and thoron (^{220}Rn, a daughter product of ^{224}Ra), and their short-lived secondary products lead to the internal exposure of the respiratory tract to alpha particles (El-Taher and Makhluf, 2010). The activity and distribution patterns of ^{226}Ra in sediment can be used to monitor the radiological impacts of the non-nuclear industries (El-Mamoney and Khater, 2004). Al-Trabulsy *et al.,* (2011), indicated that the emitted gamma radiation from natural radio elements or due to the human activities and applications is largely due to primordial radio elements, mainly ^{232}Th and ^{238}U and their daughters, as well as ^{40}K, which is existing at trace levels in the earth's crust. The natural radioactivity and the associated external exposure due to gamma radiation is depending primarily on the geological sources and the geographical status and appearing at different levels in the sediments in each region of the world (UNSCEAR, 2000). Radiation of natural origin in radioelements is responsible for most of the total radiation. The exposure to high radiation levels for a long time may lead to some diseases, chronic acute leucopenia, lung diseases, anemia and necrosis of the mouth (Suresh Gandhi *et al.,* 2014). The long time exposing to Thorium can cause lung, pancreas, hepatic, bone, kidney cancers and leukemia (Taskin *et al.,* 2009). Qureshi *et al.,* (2014), reported that the long-term exposures to radioactive elements and/or inhalation of their particles have serious health effects such as chronic lung cancer and leukemia.

Timsah Lake is highly exploited as a source of fish with net production of about 3524 tons/2015 from Timsah and Bitter lakes (GAFRD, 2015). Anglers working in the lake are reaching about 2000 in addition to 300,000 dwellers around the Lake. Elsewise, the lake used as a waiting zone for ships and cargos meanwhile its beaches exploited as recreational and tourist places. Timsah Lake receives huge amounts of wastewater daily from agriculture, industrial, freshwater and domestic drains. Under the heavy loads of sewage and wastewater runoff towards the lake, the high radiation hazards were expected and certainly, the lake fishermen may be expose to additional radiations from the anthropogenic radionuclide effluents that were accumulated in Timsah Lake sediments. exposure of humans to ionizing radiation is one of the scientific affairs that attract public attention and radiations of natural origin and non-radioactive industries are responsible for most of the total radiation exposure of the human population. Consequently, the present study aims to measure the radionuclide activities and the consequent radiation hazards in the seafloor sediments at the fishermen and recreational zones in Timsah Lake to ensure that no additional doses are imposed on to them.

2. Materials and Methods

2.1 Geological and Environmental Setting of the Lake

Timsah Lake lies adjacent to Ismailia City on the Suez Canal at about 80 km south of Port Said, Egypt (Fig. 1). It plays an important role in most of the human activities in Ismailia City such as; tourism, fisheries, navigation, etc. (Saad El-Din *et al.*, 2014). The lake has an area of about 16 km^2 and mostly shallow but reaching 16m depth in some places with capacity volume of about 90 m^3 of seawater. Timsah Lake is one of the most productive habitats in the Suez Canal region (Ahmed, 2005; Madkour *et al.*, 2006). It contains many species of the edible fishes, crustaceans and shellfish that are largely consumed by humans. On the other hand, the western and northern boundaries of the lake were intensively developed for tourism activities, aquatic sports and recreational purposes (Kamel, 2013). Timsah Lake has a unique aquatic ecosystem due to the different types of water inputs. From the western side, the lake is connected to small and shallow bay that receive about $833\times10^3 m^3$/day of treated and untreated domestic, agricultural and industrial wastewaters throughout many drains (Gabr and Gab-Alla, 2008) and occasional freshwater inputs from the Ismailia Channel. Despite the high amounts of wastewaters, the lake is threatened from other pollutant sources as ships awaiting berth and the huge Timsah Shipyard (Kaiser *et al.,* 2009) as well as the extensive human settlements whereas the domestic and industrial effluents are continuously discharged. In the last three decades the aquatic ecosystem of Timsah Lake recorded hazardous levels of pollutants of various forms; pesticides and hydrocarbons (Mostafa, 2002) and heavy metals (Gabr and Gab-Alla, 2008). The rapidly growing human activities around the Lake such as ship building and maintenance, municipal wastewater damping off and agricultural drainage loading have greatly increased the pollution hazards in the lake (Madkour *et al.*, 2006; Kaiser *et al.*, 2009) and consequently threatened the lake health, richness and diversity of indigenous fish and other plants and animals population.

2.2 Field Work

Throughout three field trips between 2016 and 2017, 24 stations covering the whole area of Timsah Lake (18 stations) and the adjacent Western Bay (6 stations) were selected for sediment sampling (Fig. 1). About one kilogram of the surface sediment was collected from each station using Grab Sampler and small engine boat. The collected samples were preserved in icebox at 20°C to avoid any changes in their natural characteristics until reach the laboratory for preparation and analysis.

2.3 Laboratory Treatment

In the laboratory, the collected samples were air dried and disaggregated by fingers to remove the agglutinated aggregates. The samples were homogenized and about 250 gm of each sample was dried in an oven at about 110°C to remove moisture from samples. The weighted samples were powdered using agate mortar to less than 80 mesh then packed in polyethylene beakers of about 350 cm^3 then sealed for 28 days to reach the secular equilibrium where the decay rate of the progeny becomes equal that of the parent (radium and thorium) and then the progeny will remain in the sample.

The activity levels of ^{238}U, ^{232}Th and ^{40}K were determined by γ-ray spectrometer at the Faculty of Science, Azhar University, Assuit, Egypt, employing a scintillation detector (3" × 3"). It is hermetically sealed assembly, which includes a NaI (Tl) crystal, coupled to PC-MCA Canberra Accuspes. The cylindrical Pb shield detector (100 mm thick) with shielded fixed bottom and movable cover was used to reduce Gamma-Ray background. This Pb shield contains an inner concentric cylinder of Cu (0.3 mm thick) in order to absorb the generated X-rays in the lead shield. The background distribution in the environment around the detector was determined using an empty sealed beaker, which was counted in the same manner and in the same geometry as the samples. The measurement time of activity or background was 720 min. To correct the net peak area of gamma rays of measured isotopes, the background spectra were used. A dedicated software program (Genie, 2000) has carried out the online analysis of each measured gamma ray spectrum. The ^{232}Th concentration was determined from the average concentrations of ^{212}Pb (238.6 keV,) and ^{228}Ac (911.1 keV) in the samples, and that of ^{238}U was determined from the average concentrations of the ^{214}Pb (351.9 keV) and ^{214}Bi (609.3 keV and 1764.5 keV) decay products. While the gamma line for ^{40}K is (1460.6 keV). The minimum detectable activity (MDA) was 25.2 Bq/kg for ^{40}K, 6.5 Bq/kg for ^{238}U and 5.7 Bq/kg for ^{232}Th as described by (Uosif, 2011; Dar *et al.*, 2015).

2.4 Radiological Hazard Indices Calculations

2.4.1 Absorbed and effective dose rate (D)

The absorbed dose rate resulted from the naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) in air at1 m above the ground. The absorbed dose rate was calculated according to UNSCEAR (2000). The conversion factors were used to compute absorbed gamma dose rate (D) in air as nGy h^{-1}, therefore *D* was calculated as follows (Eq. 1):

$$D = 0.462\ C_U + 0.604\ C_{Th} + 0.0417\ C_K \quad (1)$$

Where C_U, C_{Th} and C_k are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg, respectively.

2.4.2 The annual effective dose effect (AEDE)

The annual effective dose effect (AEDE) was calculated in (μSv/y) according the following formula (UNSCEAR, 2000) (Eq. 2):

$$AEDE= D \times 24\ hour \times 365.25\ day \times 0.2 \times 0.7 \times 10^{-6} \quad (2)$$

Whereas, D is dose rate in (nGy/h), (0.2) is the occupancy factor and (0.7) was the (conversion coefficient) in Sv/Gy (Al-Trabulsy *et al.*, 2011).

2.4.3 Radium equivalent (Ra_{eq})

Radium equivalent (Ra_{eq}) index is a widely used radiological hazard index. It is used to measure the radiation activities of samples containing different concentrations of ^{228}U, ^{232}Th and ^{40}K. It was defined on the assumption that 10 Bq/kg of ^{238}U, 7 Bq/kg of ^{232}Th and130 Bq/kg of ^{40}K to produce the same gamma dose rate (D). Radium equivalent (Ra_{eq}) was calculated from the equation according to Beretka and Mathew (1985) (Eq. 3):

$$Ra_{eq} =C_U + 1.43\ C_{Th} + 0.077\ C_K \quad (3)$$

Where C_U, C_{Th} and C_k are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg, respectively.

2.4.4 External hazard index (H_{ex})

The external hazard index (H_{ex}) represents the external radiation exposure associated with gamma irradiation from the natural radionuclides;^{228}U, ^{232}Th and ^{40}K in the investigated stations. The value of H_{ex} should not exceed the maximum acceptable value of unity in order to keep the hazard insignificant. It is calculated from the equation presented by Jankovic *et al.*, (2008) (Eq. 4):

$$H_{ex} = (C_U/370 + C_{Th}/259 + C_K/4810) \leq 1 \quad (4)$$

2.4.5 Representative level index (Iγr)

Representative level index (Iγr) was used to estimate the levels of natural radioactivity in the seafloor sediments. It must be less than unity (<1) in order to keep the radiation hazard insignificant. It is calculated based on NEA-OECD formula (1979) (Eq. 5):

$$I\gamma r = (C_U/150 + C_{Th}/100 + C_K/1500) < 1 \quad (5)$$

Whereas C_U, C_{Th} and C_K are the specific activities ($Bqkg^{-1}$) of ^{238}U, ^{232}Th and ^{40}K, respectively.

2.4.6 The excessive lifetime cancer risk (ELCR)

Excess Lifetime Cancer Risk (ELCR) is calculated based upon calculated values of AEDE, using the equation (Eq. 6):

$$ELCR = AEDE \times DL\ (70\ y) \times RF\ (0.05\ Sv^{-1}) \quad (6)$$

Where AEDE is the annual effective dose equivalent, DL is the average duration of life (70 years which is different from country to another) and RF is the fatal cancer risk per Sievert which is equal ($0.05\ Sv^{-1}$). For low dose background radiations which are considered to produce stochastic effects, ICRP 60 uses values of 0.05 for the public exposure (Taskin *et al.*, 2009).

2.5 Statistical Analyses

To illustrate the source or sources of the measured radiation indices in the lake, the correlation coefficient between each of ^{238}U, ^{232}Th and ^{40}K and the radiation hazard indices were calculated using Excel programs Ver. 7 and plotted in graphs using Wingraph Prism Ver.6. The Spatial distribution of radioactivity from sediments within the Western Bay and the Lake due to naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) and their hazardous parameters were illustrated by plotting the distribution patterns maps using Golden Software Surfer Ver. 13. Multivariate statistical analysis (multivariate component and cluster analyses using Origin Lab software Ver. 9.0) has been carried out to find out the interrelation between the measured natural radionuclides and the calculated radiation hazard parameters as well as the radioactive source(s) about the elevated radiation hazards.

3. Results and Discussion

As shown in (Table 1), ^{238}U at Timah Lake was varied between 7.03 and 56.46 with an average of 21.66 ± 11.20 Bq/kg, ^{232}Th was between 4.28 and 44.54 Bq/kg averaging of 21.42 ± 11.68 Bq/kg meanwhile, ^{40}K was fluctuated between 16.63 and 466.23 with an average of 200.30 ± 141.10 Bq/kg. Dar *et al.,* (2015) recorded that the fine particle occurrence in Timsah Lake was higher in winter than in summer because of the rate of fine and particulate sediments dispersing in winter much higher than in summer affecting by the wind, waves and the current drift toward Suez Canal in addition to the water streaming from the western Bay towards Suez Canal. The seafloor sediments of Timsah Lake tend to be fine composed of variable mixture of sand and mud with varying hues. Gab-Alla (2007) recorded that the sediment of Timsah Lake was sandy ranging from very fine sand to fine sand. Ewais *et al.*, (2000) reported that the finest sediment fractions are usually have a much greater capacity to sorb radionuclides than coarse sediments due to the great specific surface area of fine sediments and the great exchange capacity of clay minerals that are usually have the smallest particle diameters. Isinkaye and Emelue (2015) attributed the wide variation in the activity concentrations in the Oguta Lake, South East Nigeria to the influence of physical and geo-chemical processes on the accumulation of radionuclides in the sediment within the Lake. El-Reefy *et al.*, (2014) summarized that the activities of ^{226}Ra and ^{232}Th showed uniform distribution in Burullus Lake environment. They added, among the studied physical and chemical characteristics of water and sediment in Burullus Lake, only total organic matter content and salinity have the potential effects on the mobility of ^{40}K whereas, the obtained results suggested that ^{40}K was attached to different mobile particulates.

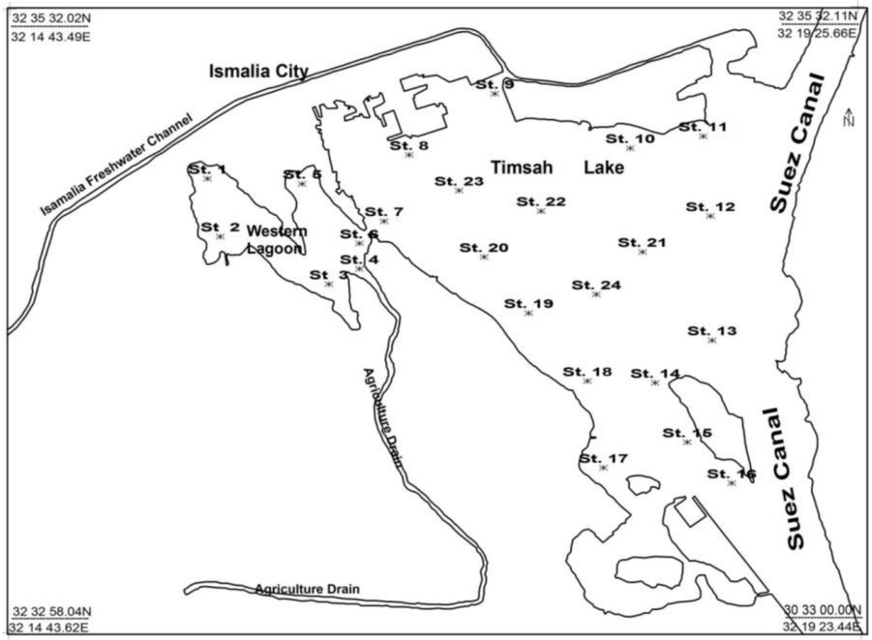

Fig. 1. Station map shows the Western Bay and Timsah Lake stations relative to Suez Canal and the sampling stations.

Table 1. The activity levels in (Bq/kg), maximum, Minimum, mean, median and the standard deviations of the measured natural radionuclides; ^{238}U, ^{232}Th and ^{40}K as well as the calculated radiation hazard parameters; Absorbed dose rate (D) (nGy/h), Outdoor Hazard index (H_{ex}), Annual effective dose equivalent (AEDE) (µSvy^{-1}), Radium equivalent (Ra_{eq}) (Bq/kg), Representative level index (Iγr) and the Excess lifetime cancer risk (ELCR×10^{-6}) in the studied samples at Timsah Lake.

S. No	^{238}U	^{232}Th	^{40}K	D	AEDE	Ra_{eq}	H_{ex}	Iγ	ELCR
1	10.21	4.28	36.83	8.81	10.80	19.16	0.05	0.06	37.81
2	22.49	16.57	16.63	21.08	25.85	47.46	0.13	0.16	90.48
3	26.92	34.82	305.68	46.00	56.42	100.25	0.27	0.34	197.46
4	17.62	14.76	102.17	21.25	26.06	46.60	0.13	0.16	91.20
5	7.03	8.79	58.72	10.96	13.44	24.12	0.07	0.08	47.05
6	19.52	21.02	167.89	28.60	35.07	62.50	0.17	0.21	122.75
7	16.04	22.97	37.89	22.84	28.01	51.80	0.14	0.18	98.02
8	33.63	43.72	290.48	53.86	66.05	118.52	0.32	0.40	231.17
9	12.82	5.17	141.43	8.14	9.99	15.96	0.04	0.05	34.95
10	27.32	24.90	199.11	35.83	43.94	78.26	0.21	0.27	153.79
11	17.66	7.24	327.90	26.20	32.13	53.79	0.15	0.18	112.45
12	23.08	25.15	466.23	44.97	55.15	94.95	0.26	0.32	193.03
13	33.56	29.24	399.02	49.52	60.74	106.10	0.29	0.36	212.58
14	8.05	7.32	79.83	11.41	14.00	24.67	0.07	0.08	49.00
15	10.99	12.68	33.45	14.11	17.30	31.70	0.09	0.11	60.56
16	10.58	15.25	181.11	20.72	25.42	44.44	0.12	0.15	88.96
17	17.76	21.23	149.84	27.17	33.32	59.65	0.16	0.20	116.62
18	21.34	33.89	217.17	39.23	48.11	86.52	0.23	0.29	168.39
19	14.69	16.53	90.12	20.47	25.10	45.27	0.12	0.15	87.85
20	34.41	34.95	457.10	55.75	68.37	119.58	0.32	0.40	239.29
21	35.25	31.18	202.31	43.41	53.24	95.42	0.26	0.32	186.35
22	22.18	24.66	195.37	33.15	40.66	72.49	0.20	0.25	142.31
23	20.19	13.23	191.01	25.15	30.84	53.81	0.15	0.18	107.94
24	56.46	44.54	459.89	71.84	88.11	155.57	0.42	0.53	308.38
Max	56.46	44.54	466.23	71.84	88.11	155.57	0.42	0.53	308.38
Min.	7.03	4.28	16.63	8.14	9.99	15.96	0.04	0.05	34.95
Av.	21.66	21.42	200.30	30.85	37.84	67.02	0.18	0.23	132.43
Median	19.85	21.12	186.06	26.68	32.72	56.73	0.15	0.19	114.53
St Dev.	11.20	11.68	141.10	16.75	20.55	36.25	0.10	0.12	71.91

According the distribution maps of the radioactive elements ^{238}U, ^{232}Th and ^{40}K, the highest levels of these elements were observed inside the Western Bay in front of wastewater and agriculture drains and at the water stream path towards Timsah Lake (Fig. 2 (a,b,c)) indicating that the anthropogenic sources are the main effluents of these radioactive elements due to the high fine sediments income from the different sewage, industrial and agriculture drains. Dar and El Saharty (2013a,b) suggested that the drainage systems of at Marriot and Burrullus lakes that dishcharged wastes of the fertilizers, petrochemical, paper industries, agricultural draining waters and salines in addition to the particulate radionuclides that come from the neighbouring localities and the huge inputs of terrigenous materials are the main sources of the recorded activities. They concluded that the fine-grained sediments rich in organic matter in and the particulate matters that come from the neighbouring localities with the marine currents are adsorbing the radionuclides. Fahmi *et al.*, (2010) attributed the highest levels of ^{238}U, ^{232}Th and ^{40}K in Idku Lake to the human activities. Jacobi (1990) considered phosphate industry was the major source of radioactivity in the marine environment. He attributed the high levels of natural radionuclides to the industrial operations involving phosphate ores.

The recorded activity average of ^{238}U at Timsah Lake in this study was higher than the recorded activities in Marriott and Burrllus lakes by Dar and El Saharty (2012), some localities at the western side of the Red Sea (El Saharty and Dar, 2010; Dar and El Saman, 2012; Salama *et al.,* 2015) but lower than Safaga Therapy Site (El-Arabi 2005), Hamrawin Phosphate Harbour (Dar and El Saman, 2012), Arabian Gulf (El-Taher *et al.,* 2018), Historical City Panipat, India (Amanjeet *et al.,* 2017), Tudor Shaft Mine, South Africa (Njingaand Tshivhase, 2016) and Oguta Lake, Nigeria (Isinkaye and Emelue, 2015) and nearly equal the recorded values at Hurghada, Red Sea (El-Arabi 2005). The average activities of ^{232}Th in the studied lake was higher than Arabian Gulf (El-Taher *et al.,* 2018), some localities western the Red Sea (El Saharty and Dar, 2010; Dar and El Saharty, 2012; Dar and El Saman, 2012; Salama *et al.,* 2015) and lower than Historical City Panipat, India (Amanjeet *et al.*, 2017), Tudor Shaft Mine, South Africa (Njinga and Tshivhase, 2016) and Oguta Lake, Nigeria (Isinkaye and Emelue, 2015) but nearly equal Safaga Therapy Site and Hurghada (El-Arabi, 2005). The recorded average activities of ^{40}K at Timsah Lake were higher than Arabian Gulf (El-Taher *et al.,* 2018), Tudor Shaft Mine, South Africa (Njinga and Tshivhase, 2016), some localities western the Red Sea (Salama *et al.,* 2015) but significantly lower than Historical City Panipat, India (Amanjeet et al., 2017), Oguta Lake, Nigeria (Isinkaye and Emelue, 2015), Marriott and Burrllus lakes, Egypt (Dar and El Saharty, 2012), some localities at the western side of the Red Sea (El-Arabi, 2005; El Saharty and Dar, 2010; Dar and El Saman, 2012) (Table 2).

Monitoring the release of gamma radiation from natural radionuclides is important to protect the humans from lung cancer. Sustained exposure to the high background radiations may pose substantial health threats to general public (Rafique *et al,* 2014). Some of the radiation health effects are chronic lung diseases, acute leucopoenia, anemia and necrosis of the mouth. Thorium exposure can cause lung, pancreas, hepatic, bone, kidney cancers and leukemia (Taskin *et al.,* 2009). The means of absorbed dose rate (D), annual effective dose rate (AEDE), radium equivalent (Ra_{eq}), external hazard index (H_{ex}), and the representative level index (Iγr) at Timsah Lake were; 30.85 ± 16.75 nGy/h, 37.84 ± 20.55 µSvy^{-1}, 67.02 ± 36.25 Bq/Kg, 0.18 ± 0.10 and 0.23 ± 0.12 respectively. The mean of Excess Lifetime Cancer Risk (ELCR) was 132.43 ± 71.91 (Table 1). The mean of the calculated radiological hazards were lower than the average recorded in UNSCEAR, (2000). The distribution patterns maps illustrated that some stations recorded relatively high levels especially at the Western Bay and at the interlink path between the bay and the Lake. These high levels were accompanied with the recorded high natural radiation levels suggesting that the wastewater runoff from the different drains is the source of high radiation levels that follow the water stream (Fig. 3). The significant decline of both the natural radionuclide elements and radiation hazard parameters in the different stations inside Timsah Lake indicated that the anthropogenic loads of wastewater come from the Western Bay are dispersed toward Suez Canal and the recreational zones and fishing sites were radiologically safe.

The calculated radiation hazards at Timsah Lake in the present study were higher than El-Sallam Canal Egypt (Ramadan *et al.,* 2018), Arabian Gulf of Saudi Arabia (El-Taher *et al.,* 2018), some localities at the Red Sea (Salama *et al.,* 2015) Burullus Lake (Dar and El Saharty, 2012) and Suez Canal (El-Tahawy *et al.,* 1994). The radiation hazard parameters were lower than the world average (UNSCEAR, 2000), Idku Lake , Egypt (Fahmi *et al.,* 2010), Oniru Beach and Oguta Lake, Nigeria (Oluwaseyi *et al.,* 2018; Isinkaye and Emelue, 2015), Panipat City India (Amanjeet *et al.,* 2017), Tudor Shift Mine, S. Africa (Njinga and Tshivhase, 2016), some localities at the Red Sea (Dar and El Saman, 2012; El Saharty and Dar, 2010; El-Arabi, 2005), Burullus Lake (El-Reefy *et al.,* 2010) and Beach of Acra, Ghana (Lawluvi *et al.,* 2011) but nearly equal the estimated results at Marriott Lake (Dar and El Saharty, 2012), Rasel Behar Red Sea (Dar and El Saman, 2012), Nasser Lake (Khater *et al.,* 2005) and North East Coast of Tamilnadu, India (Ramasamy *et al.,* 2009) (Table 3).

The distribution pattern maps (Fig. 3) showed that the highest activity levels of the different radiological hazard parameters were concentrated in the Western Bay and in the interlink path between the bay and the lake, meanwhile the whole Lake surface showed minimized activities lower than the world average recorded by UNSCEAR, (2000) especially at the fishing and recreational zones. The correlation coefficient showed significantly high correlations between the radiation hazard parameters with ^{238}U and ^{232}Th much more than ^{40}K indicating to both ^{238}U and ^{232}Th are the main sources of the elevated hazards in the lake (Table 4).This illustration was assured by the multivariate component analysis diagram and Cluster analyses diagram. They were sequestered^{238}U and ^{232}Th with the different radiation hazard parameters together in one component (Fig. 4) and clustered in one cluster (Fig. 5), meanwhile ^{40}K was sequestered in another component segment and clustered alone.

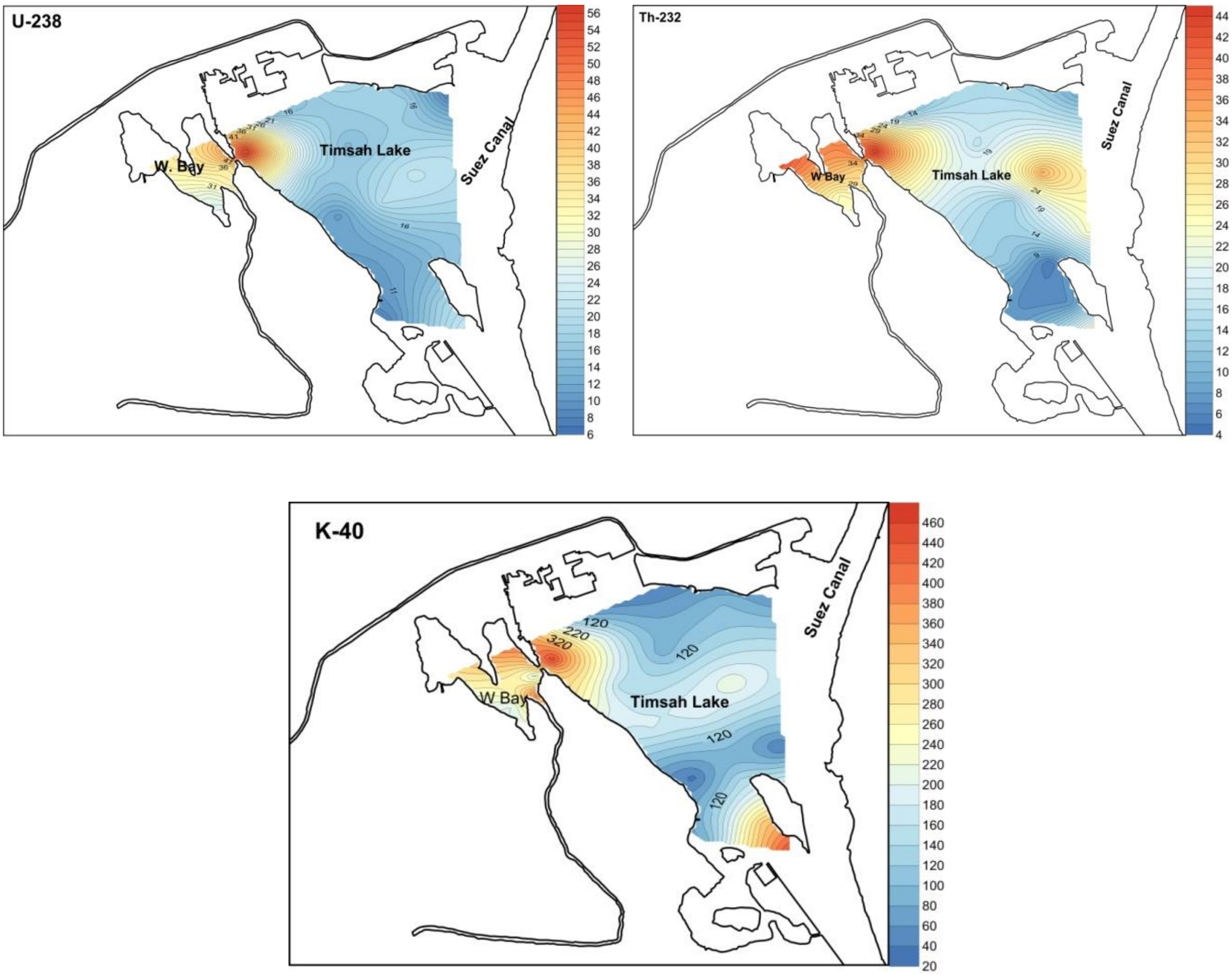

Fig. 2. The distribution patterns of 238U, 232th and 40K in the Western Bay and Timsah Lake.

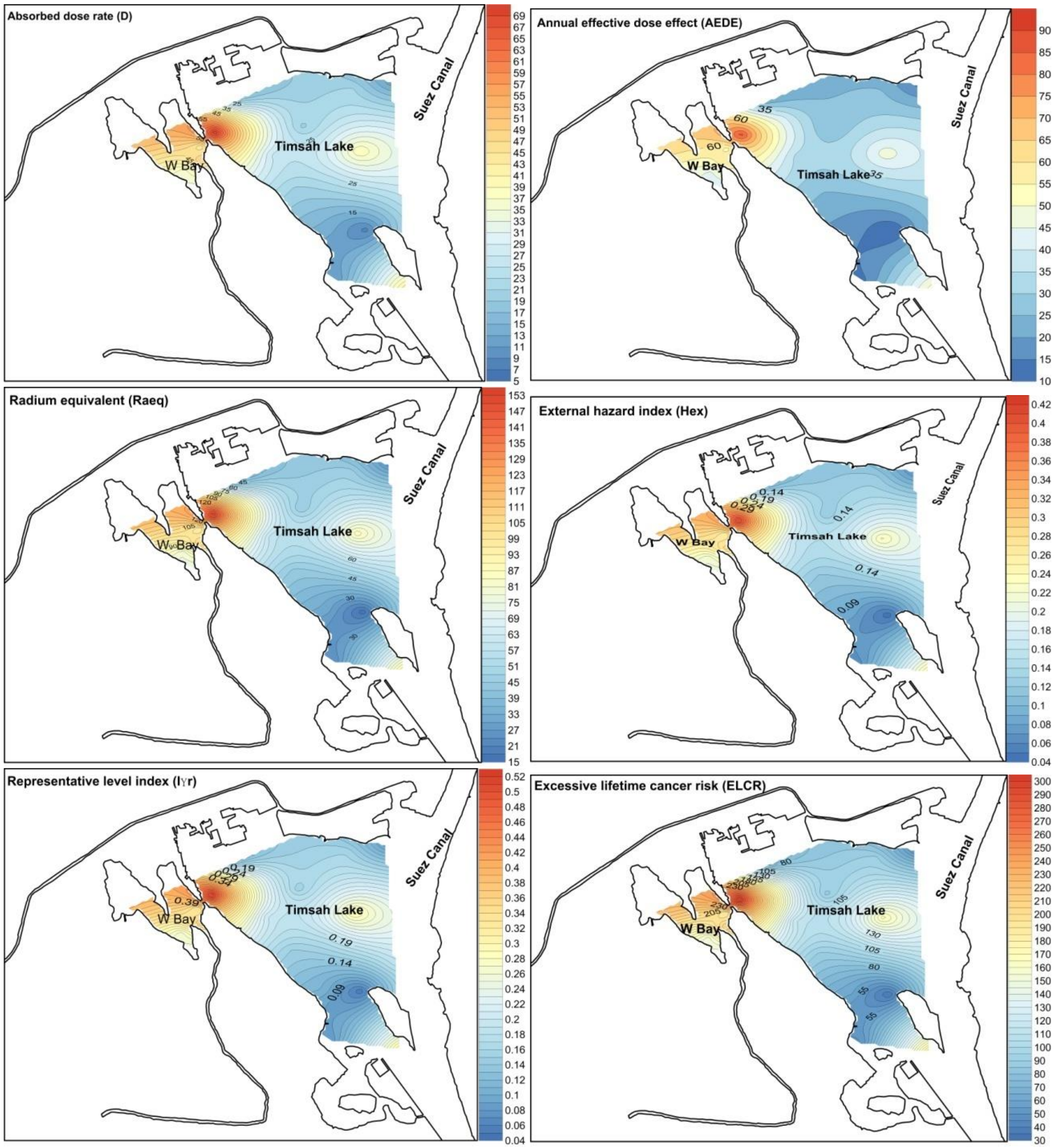

Fig. 3. The distribution patterns of the radiation hazard indices showed the zones of high levels at the Western Bay and Timsah Lake.

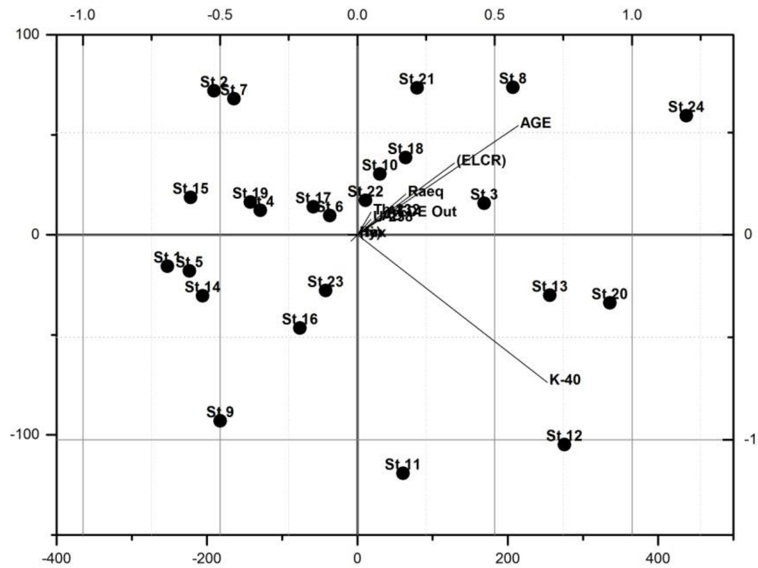

Fig. 4. Multivariate component analysis sequestered 238U and 232Th with the different radiation hazards in one component and 40K alone.

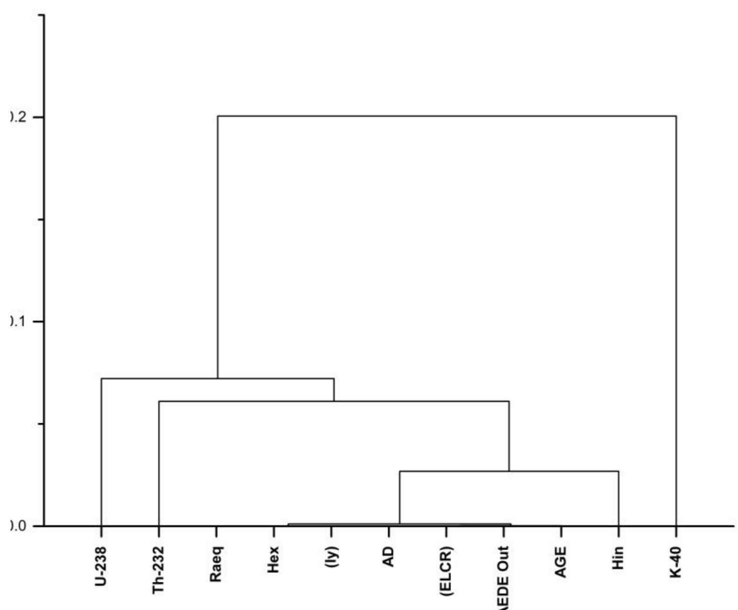

Fig. 5. Cluster analysis using Word's Method illustrated the interaction between 238U and 232Th with the different radiation hazards rather than 40K which clustered alone.

Table 2. Comparison between the averages of the recorded natural radionuclides at Timsah Lake with some of the other worldwide studies.

	U-238	Th-232	K-40	Station	Reference
Egypt	21.66	21.42	200.3	Timsah Lake	Present work
Egypt	16.18	13.66	264.42	El-Salam Canal	Ramadan *et al*., 2018
S. Arabia	36.32	6.21	169.4	Arabian Gulf	El-Taher *et al*, (2018)
Nigeria	*56.65*	*53.11*	*603.52*	Oniru Beach Lagos	Oluwaseyi *et al*., 2018
India	30.24	29.89	291.06	Historical city Panipat	Amanjeet *et al*., (2017)
S. Africa	271.96	47.65	87.17	Tudor Shaft mine	Njinga and Tshivhase (2016).

Nigeria	47.89	55.37	1023	Oguta Lake	Isinkaye and Emelue 2015
Egypt	9.2	6.6	172.15	Red Sea	Salama *et al*., 2015
Egypt	17.22	10.03	299.7	Burullus Lake	Dar and El Saharty, 2012
Egypt	12.65	7.24	518.75	Mariot Lake	Dar and El Saharty, 2012
Egypt	15.2	16.2	330.7	Rasel Behar, Red Sea	Dar and El Saman, 2012
Egypt	114.2	14.8	253.9	Hamrawin, Red Sea	Dar and El Saman, 2012
Ghana	11.00-31.80	16.80-231.2	68.3 – 183.9	Beaches of Acra	Lawluvi, *et al*., (2011)
Egypt	16.76	10.15	593.01	Red Sea sediments	El Saharty and Dar 2010
Egypt	14.3	20.0	312	Brullus Lake	El-Reefy *et al*., 2010
Egypt	20.37	26.05	329.05	Idku Lake	Fahmi *et al*., 2010
Egypt	25.3	21.4	618	Safaga, Red Sea	El-Arabi 2005
Egypt	20.6	22.4	548	Hurghada, Red Sea	El-Arabi 2005
Egypt	14.3 – 22.0	18.4 – 24.4	222 – 326	Nasser Lake	Khater *et al*. 2005

Table 3. The radiological hazard parameters calculated in the sediment samples compared with the worldwide studies.

	D (nGy h-1)	AEDE (µSv/y)	Ra_{eq} (Bq/kg)	H_{ex}	Iγr	ELCR	Station	Reference
Egypt	30.85	37.84	67.02	0.18	0.23	132.43	Timsah Lake	Present work
Egypt	27.14	33.28	56.06	0.15	0.42	-	El-Salam Canal	Ramadan *et al*., 2018
S.Arabia	16.09	33.84	33.08	0.16	0.25	118.45	Arabian Gulf	El-Taher *et al*, (2018)
Nigeria	*83.42*	102.31	179.1	0.5	1.3	350	Oniru Beach Lagos	Oluwaseyi *et al*., 2018
India	44.16	54.16	93.41	0.24	0.69	189.56	Historical city Panipat	Amanjeet *et al*., (2017)
S.Africa	158.06	193.84	346.81	0.94	2.35	678.46	Tudor Shaft mine	Njinga and Tshivhase (2016).
Nigeria	186.8	92	205.67	0.56	1.2	321	Oguta Lake	Isinkaye and Emelue 2015
Egypt	15.7	19.25	32.2	0.07	0.24	67.38	Red Sea	Salama *et al*., 2015
Egypt	26.62	32.65	59.17	0.15	0.42	114.26	Burullus Lake	Dar and El Saharty, 2012
Egypt	32.01	39.26	70.19	0.17	0.5	137.4	Mariot Lake	Dar and El Saharty, 2012
Egypt	30.69	37.65	63.81	0.17	0.48	131.776	Rasel Behar	Dar and El Saman, 2012
Egypt	72.35	88.73	154.88	0.42	1.08	310.56	Hamrawin	Dar and El Saman, 2012
Ghana	54.08	66.32	101	0.27	0.71	232.133	Beaches of Acra	Lawluvi *et al*., (2011)
Egypt	38.78	47.56	76.94	0.21	0.61	166.46	Red Sea sediments	El Saharty and Dar 2010
Egypt	31.79	38.99	66.92	0.181	0.5	136.455	Brullus Lake	El-Reefy *et al*., 2010
Egypt	36.06	44.22	73.94	0.2	0.56	154.784	Idku Lake	Fahmi *et al*., 2010
Egypt	50.38	61.79	103.49	0.28	0.8	216.27	Safaga, Red Sea	El-Arabi 2005
Egypt	45.9	56.29	94.828	0.26	0.73	197.01	Hurghada, Red Sea	El-Arabi 2005
Egypt	32.66	40.05	69.47	0.187	0.52	140.19	Nasser Lake	Khater *et al*. 2005
Egypt	26.45	32.44	56.66	0.153	0.42	113.534	Suez Canal	El-Tahawy *et al.* 1994
World Average	60.07	73.67	129.69	0.35	0.95	257.84	-	UNSCEAR, (2000)

Table 4. Correlation coefficient relationships between the natural radionuclides and the calculated radiation hazard parameters.

	U-238	**Th-232**	**K-40**
Ra_{eq} (Bq/Kg)	0.94	0.94	0.83
D (nGy h^{-1})	0.93	0.93	0.85
AEDE(µSv/y)	0.93	0.93	0.85
Hex	0.94	0.94	0.83
(Iγ)	0.94	0.95	0.83
(ELCR)	0.93	0.93	0.85

4. Conclusion

- Timsah Lake is located at the midpoint of Suez Canal. It is highly exploited in fishing and recreational activities as well as it was used as waiting area for ships. The lake has unique ecosystem as it was considered one of the highly fish productive lakes.
- The lake receives as much as 833×10^3 m^3/day of untreated wastewater from agriculture, industrial and domestic drains.
- The natural radionuclide elements ^{238}U and ^{232}Th and ^{40}Kwere measuredusing gamma ray spectrophotometer in 24 stations covering the whole area (Western Bay and the lake) and the radiation hazards parameters were calculated.
- Significant variations were observed between the different stations, Western Bay stations and the interlink path between the bay and the lake recorded the highest activities and radiation hazards indicating to the wastewater runoff from the different drains was the source of the elevated activities and hazards.
- Statistical analyses indicated that ^{238}U and ^{232}Th are responsible for the elevated radiations especially in the Western Bay.
- The investigated stations inside Timsah Lake recorded average activities and radiation levels lower than the worldwide average indicating safe situation especially in the fishing zones and recreational resorts.

The calculated excessive lifetime cancer risk was mostly within the safe limits especially in the zones of high exploitation.

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مخاطر الإشعاع وتقييم مخاطر الإصابة بالسرطان في رواسب بحيرة التمساح، مصر

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المستخلص. بحيرة التمساح من أكثر البحيرات إنتاجا للأسماك في مصر. تقع في منتصف قناة السويس وتبلغ مساحتها حوالي ١٦ كيلومتر مربع. تستقبل البحيرة حوالي ٨٣٣٠٠٠ متر مكعب يومياً من مياه الصرف الصحي ومخلفات الصرف الصحي من الزراعة والصناعة والمصارف المنزلية. تركيزات نشاط النويدات المشعة الطبيعية؛ تم قياس ^{238}U و ^{232}Th و ^{40}K باستخدام مقياس الطيف الضوئي لأشعة جاما في ٢٤ محطة تغطي كامل مساحة البحيرة والخليج الغربي. متوسط الأنشطة ^{238}U و ^{232}Th و ^{40}K كانت: ٢١,٦٦ ± ١١,٢٠ و٢١,٤٢ ± ١١,٦٨ و٢٠٠,٣٠ ± ١٤١,١٠ بيكريل / كغ على التوالي. ومتوسطات عوامل الخطر الإشعاعي؛ معدل الجرعة الممتصة والفعالة (D)، المكافئ السنوي للجرعة الفعالة (AEDE)، ومكافئ الراديوم (R_{aeq})، ومؤشر الخطر الخارجي (H_{ex})، ومؤشر المستوى التمثيلي ($I\gamma r$)؛ هي: ٣٠,٨٥ $nGy\ h^{-1}$ و٣٧,٨٤ $\mu Sv/y$ و٦٧,٠٢ Bq/kg و٠,١٨ (أقل من الوحدة) و٠,٢٣ على التوالي. كما أظهرت أنماط التوزيع اختلافات كبيرة في أنشطة النويدات المشعة ومعلمات الخطر بين المحطات التي تم فحصها. وأظهرت محطات الخليج الغربي ومنطقة المسار المترابطة بين الخليج والبحيرة أنشطة النويدات المشعة العالية، ومخاطر الإشعاع العالية التي تشير إلى نفايات الصرف الصحي، وجريان مياه الصرف الصحي هي المصادر الأساسية لأنشطة النويدات المشعة الطبيعية العالية ومخاطر الإشعاع. كان متوسط خطر الإصابة بالسرطان مدى الحياة (ELCR) 132.43×10^{-6} أقل بكثير من المتوسط العالمي. وبلغ أعلى مستوى تم تسجيله من ELCR 308.38×10^{-6}، وهو ما لوحظ في منطقة الارتباط بين الخليج والبحيرة بعيداً عن محطات الصيد والمناطق الترفيهية. أشارت التحليلات الإحصائية إلى أن النويدات المشعة ^{238}U و ^{232}Th هي مصادر مخاطر الإشعاع المرتفعة مع شدة متساوية تقريباً.